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SEARCH FOR RESONANT BHABHA SCATTERING AROUND AN INVARIANT MASS OF 1.8 MeV

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A search was made for resonant Bhabha scattering of positrons on atomic electrons using two Mini-Orange spectrometers and relatively thick targets of low Z. No resonances were found within ($\sigma_{res}\,\Gamma$) limits of $\simeq$20 to 40 barn eV for lifetimes in the 10^{-10}–10^{-12} s range of an intermediate particle propagating freely in the target material.

The puzzling observations of correlated (e^+e^-) events emitted in "superheavy" collisions [1,2] has provoked the hypothesis of the production and subsequent decay of a new elementary or composite particle [#1]. The question was raised whether resonances could be observed in the time-reversed process of Bhabha scattering, in absence of the particular conditions of heavy-ion collisions with strong electric and magnetic fields. In the conventional description of Bhabha scattering the cross section decreases smoothly with energy. Structure should occur in the case a neutral particle X exists which can decay into (e^+e^-) pairs [6]. Until recently, the occurrence of resonant Bhabha scattering was never investigated in the MeV region. Yet, the GSI findings precisely pointed to the possibility of a strong but conceivably narrow resonance in this region. The first experiments with low-Z targets were reported this year [7–10]. They are partly hampered by limited resolution, low count rates and lack of suitable e^+ beams and signal a process of finding optimal strategies.

Here, we report on a method in which the background of non-resonant events is shifted to below the energy region in which resonances are searched for. Restricting ourselves to lifetimes not much shorter than 10^{-12} s, it was allowed to use relatively thick targets. In fact, these lifetimes cover a region of interest as can be inferred from ref. [6]. We will first discuss some basic restrictions on the experimental resolution for resonant Bhabha scattering, then describe the method and finally present the results.

Since the use of colliding beams is not within scope, the positrons must be scattered on atomic electrons. This implies that the energy resolution suffers from momentum broadening by the motion of the target electrons. A minimum broadening is rather important, since this effect determined exclusively the resolution ΔE of the following experiment. In low-Z atoms or in chemical bonds of low-Z molecules the electrons are relatively "quiet". For instance, in polyethylene or $(CH_2)_n$ half of the electrons are in C–H and one quarter in C–C bonds. The other quarter, formed by inner-shell C-electrons, has too large a momentum spread for searches of sharp reso-

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[#1] This subject is related to the finding of narrow positron lines by both the EPOS [1] and the ORANGE [3] Collaborations and has been widely discussed at various conferences [4,2]. Recent references are in a report of Soff et al. [5].

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nances. To gain some insight in e^- momentum distributions we observed the well-known broadening of annihilation radiation in various materials. The broadening at 511 keV is less than at 1.8 MeV invariant mass, but it could readily be observed with a Ge detector with 1.7 keV resolution. The total 511 keV width proved to be relatively narrow ($\cong$2.37 keV) for lucite and polyethylene and broader (2.8–3.1 keV) in Be, C or H_2O. A further advantage of the low-Z molecules is their relatively small fraction of inner-shell electrons. Judging in addition Compton profiles as discussed by Cooper [11], we decided to use easily available lucite as a low-Z material. Tentatively, we adopted $\Delta E = 12$ keV.

The measurements were focussed on an invariant mass m_X of about 1.8 MeV, corresponding to events observed by the EPOS Collaboration [1]. With e^- at rest this implied that the incident positrons must have a kinetic energy $E(e^+_{inc}) = m_X^2c^4/2mc^2 - 2mc^2 \cong$ 2.3 MeV and that the neutral boson X would move with a velocity of $0.82c$. We make the assumption that this neutral particle X moves in essence freely through the target layer. In the case it exists sufficiently long to decay outside the target, the emitted (e^+e^-) pairs will cause a "sharp" sumpeak with a width ΔE, by which X might be recognized. In the present experiment $E(e^+_{inc})$ was varied in two ways: actively by performing different runs with a different mean energy of the positrons falling on the target, and passively by the fact that during each run the positrons slowed down continuously in an energy-loss range of 210 keV. For $\tau_X > 10^{-11}$ s nearly all resonant pairs ($\geqslant 90\%$) will decay outside the target. In contrast, the ejectiles from prompt non-resonant events originate inside the target. They experience more than twice the dE/dx value of the incoming positrons and drop in energy to below the signal of resonant events. Thus the use of thicker targets and the energy determination after scattering offered three advantages: a reduced background, a more efficient use of the incident positrons, and an experimental resolution which is solely determined by the momentum broadening with atomic electrons.

The Bhabha spectrometer is sketched in fig. 1. It used positrons selected from the β^+-ray continuum of a ^{27}Si (4.2 s, 3.8 MeV) source of $\simeq$0.3 Ci. This source was produced on-line in a water cooled 1.5 mm thick Al target via the $^{27}Al(p,n)$ reaction with pro-

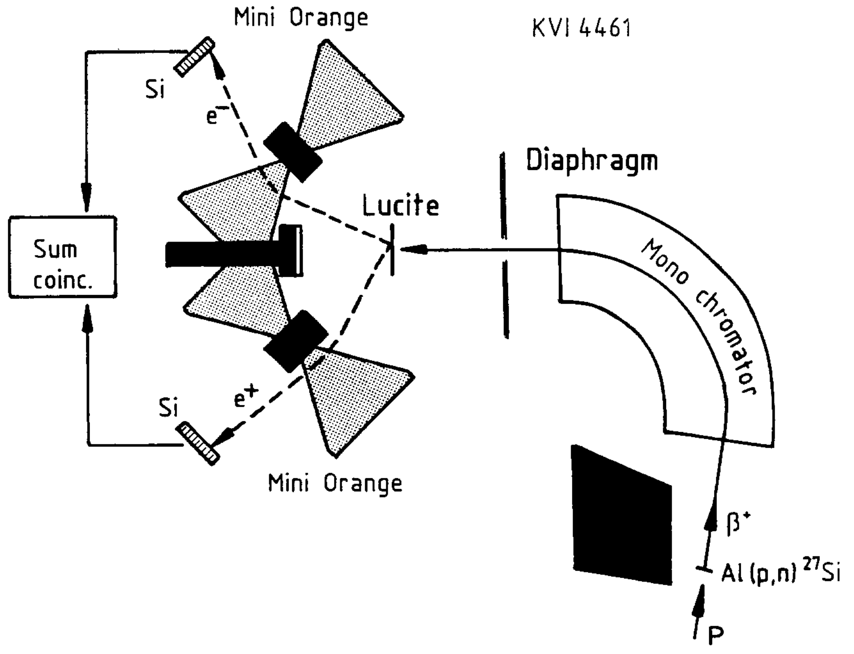

Fig. 1. Bhabha spectrometer incorporating two Mini-Orange devices to observe e^+ and e^- ejectiles. Incident e^+ particles were selected with the monochromator from the ^{27}Si β^+-ray continuum. Lead shieldings are in black.

tons of 17 MeV from the KVI cyclotron. A doubly focussing magnetic sector field transmitted more than 10^5 e^+/s around 2.3 MeV towards the scatterer of 1 mm lucite with a width of 140 keV. This width was clearly visible in singles Si(Li) spectra taken from positrons which were first transmitted and then Mott-scattered by a thin Th foil. During the measurements, an appropriate diaphragm reduced unwanted contributions from scattering by edges and walls. One Mini-Orange spectrometer, detecting e^+ and rejecting e^- ejectiles, was equiped with a 3 mm thick Si(Li) detector; the other Mini-Orange with an opposite magnetic field for e^- (rejecting e^+) ejectiles had a 5 mm Si(Li) detector. The Mini-Oranges were taken from a previously used fourfold arrangement [12], but were in essence as described in ref. [13]. The detectors observed (e^+e^-) coincidences with a time resolution of ≅ 7 ns. The measurements proceeded in alternating periods of 2.5 s activation followed by 2.5 s of event accumulation. Energy and time signals were stored in event-by-event mode. Radiation damage by the (p,n) neutrons gradually deteriorated[#2] the Si(Li) resolution to twice the original FWHM of 2.5 keV. The e^+-Si(Li) response to the annihilation radiation caused a summation-tail, responsible for the remaining background in the region of interest. The transmission of the e^--Mini-Orange covered smaller scattering angles (20°–32°) and larger energies (1.0–1.6 MeV) than the transmission of e^+-one (around 33° and 1 MeV). These settings favoured the resonant scattering with respect to the non-resonant scattering, since the latter increases with small energy transfers [6]. The acceptance of the Mini-Oranges was about 3% of 4π; slightly more for the e^+ and slightly less for the e^- one. Background from cosmic muons, Compton-scattered γ rays and annihilation-induced coincides was negligible. Bremsstrahlung was insignificant because of the low Z of the target and the insensitivity of Mini-Orange spectrometers to photons originating from the scatterer.

The accumulated (e^+e^-) spectra showed no peaks but yielded bounds. The steps of the analysis are displayed in fig. 2, starting with the (e^+e^-) sum spectrum. The energy scale of this spectrum was

[#2] Terminating the experiment. Future work will need a design in which the present distance of 30 cm between activation- and measurement-site is enlarged.

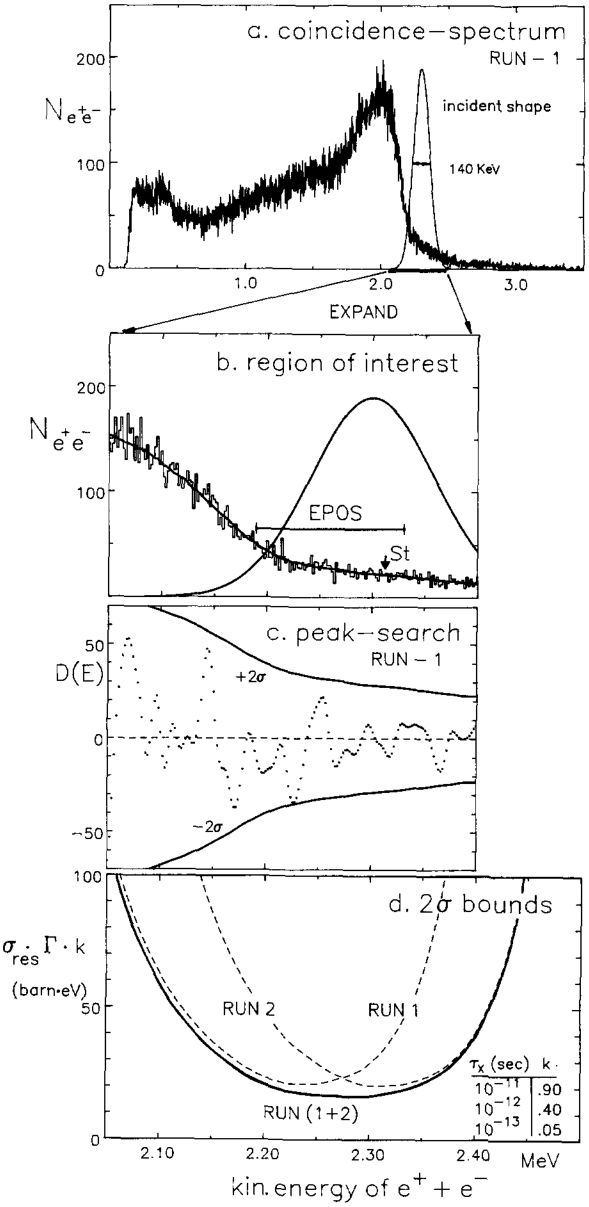

Fig. 2. (a) Spectrum of (e^+e^-) energy sums obtained with 1 mm lucite and incident positrons of 2.3 MeV (Run-1, randoms subtracted). (b) Region of interest with least-squares fit to residual background from non-resonant Bhabha events. At St ref. [7] reached a maximum deviation. The range corresponding with EPOS (e^+e^-) events at 810 keV is indicated. (c) Deviations $D(E)$ fluctuate statistically within 2σ bounds as explained in the text. (d) Final $+2\sigma$ bound on $\sigma_{res}\Gamma$ from two combined runs (thick line). The factor k, given in the inset, accounts for the influence of the lifetime.

determined within 1 keV using calibration sources. Although the monochromator setting could be adjusted to within only 30 keV, the mean incident energy could be more precisely established from the (e^+e^-) spectra by taking into account energy losses and by comparing the data with some results (not shown) obtained with thin scatterers. The spectrum of incident positrons is indicated by the drawn line. Inside the 1 mm lucite this spectrum is shifted [14] by 210 keV and broadened [15] by energy-loss fluctuations to about 200 keV. The (e^+e^-) spectrum of non-resonant Bhabha events still reflects the incident distribution, but is further broadened because the two ejectiles travelled under oblique angles with lower mean velocities. The low-energy tail of the spectrum is caused by backscattering at detector and magnet surfaces, by exceptional pathways of ejectiles inside the target, and to a lesser extent by bremsstrahlung. The effective incident flux was implicitly monitored by the observed non-resonant events. Taking one of our two main runs as an example, the number of events between 1.7 and 2.2 MeV amounted to 32000. Adopting a background of 12% from interpolated spectral intensities at lower and higher energies, we used a number $N_t = 28000$ of non-resonant Bhabha events for normalization of the number of possible resonance events. This estimate of N_t is conservative, since a part of the coincidences below 1.7 MeV still originated from valid non-resonant Bhabha events.

The region of interest (fig. 2b) was searched for a possibly significant peak in form of a deviation $D(E)$ from a smooth least squares fit to the region. At each energy channel E, $D(E)$ was taken as the area (positive, zero or negative) of a single gaussian peak with $\Delta E = 12$ keV. The sequence of deviations fluctuated (see fig. 2c) "at random" between statistical -2σ and $+2\sigma$ limits derived from the smooth fit. Thus, the latter $+2\sigma$ limit was adopted as an upper bound for $D(E)$. We ascertained that this bound is not critically affected by the adopted value of ΔE: the 2σ limit increases with $\sqrt{\Delta E}$, but searches with ΔE twice as small or twice as large yielded no peaks either.

Let each channel E have been passed by a fraction $g(E)$ of the number of slowed down e^+_{inc} particles. When E lies in or near the middle of the region of interest, this fraction was large ($\geqslant 0.8$), but going 0.2 MeV towards the outsides it became small ($\leqslant 0.1$). The number of non-resonant events $N(E) = g(E)N_t$ is related to cross sections by

$$\sigma_{\text{res}}\Gamma = D(E)\sigma_{\text{Bh}}\Delta E^*/N(E)d'fk\,. \tag{1}$$

Here, Γ denotes the intrinsic and ΔE^* the experimental width in the center of mass; $d' = \Delta E/d \cdot \langle -\mathrm{d}E/\mathrm{d}x\rangle = 0.047$ is the effectively used fraction of the target thickness; f is the fraction of effective target electrons (adopt 0.7); k is the fraction of $X \to e^+ + e^-$ decays outside the target (see the inset of fig. 2d). The cross section σ_{Bh} for non-resonant scattering amounts to $\cong 0.17$ barn for e^- angles ranging from 20° to 32°.

Run-1 was complemented with the similar run-2 at 80 keV higher incident energy. Around 2.2–2.3 MeV the final 2σ bound (fig. 2d) is most restrictive for a lifetime of about 10^{-11} s with $\sigma_{\text{res}}\Gamma < 18$ barn eV. This limit is twice as narrow as the one in ref. [7] and considerably narrower than in refs. [8,9]. In the case $\tau_X = 10^{-12}$ s the limit is still 41 barn eV but for 10^{-13} s it becomes 330 barn eV. In the case X exists with a very long lifetime ($\geqslant 10^{-10}$ s) it decays outside the effective Mini-Orange source area.

Theoretical considerations [6] make it desirable to continue the searches with increased sensitivity in the $\tau = 10^{-11}$–10^{-12} s range with the above thick targets and to cover 10^{-13} s lifetimes with thinner targets. Experimentally, we foresee as relevant possibilities: (i) Removal of the background from the annihilation–summation tail by requiring 511 keV coincidences in the experiments with a thick scatterer; (ii) Alternatively: abandon the thick target and match its thickness to the above value of d' in order to remove lifetime constraints; (iii) Introduction of more efficient (e^+e^-) accumulation and higher e^+_{inc} fluxes; and (iv) Scattering of polarized positrons by polarized electrons [16].

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